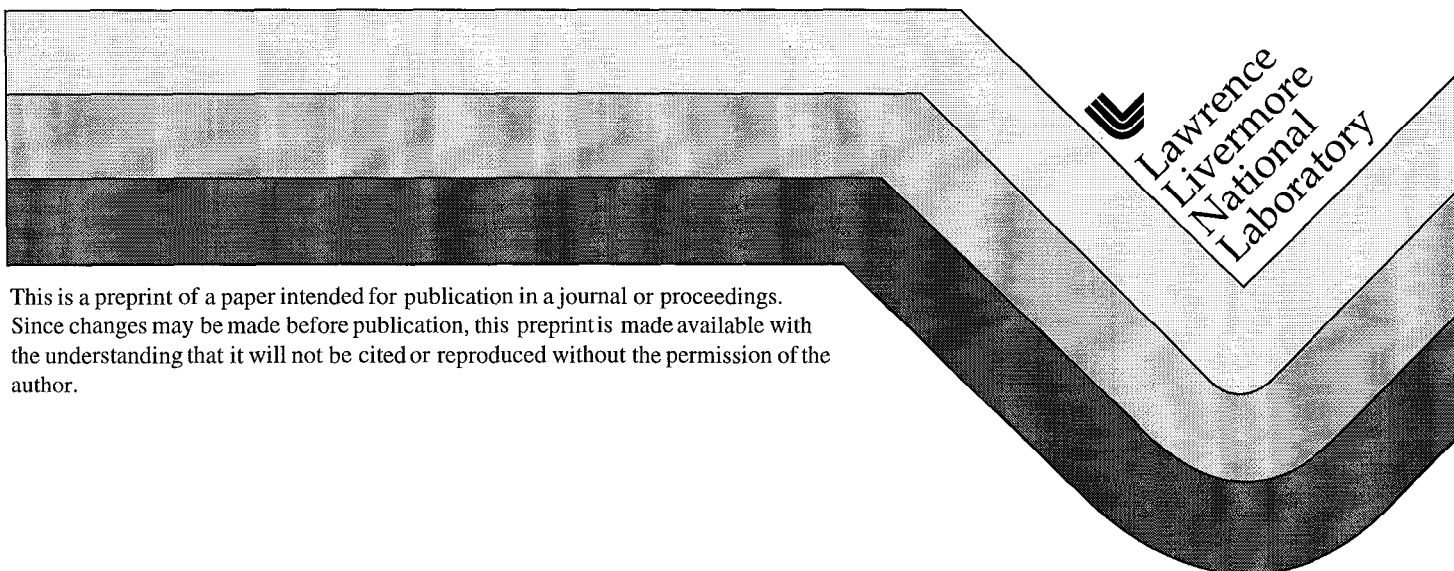# Signal Analysis Approach to Ultrasonic Evaluation of Diffusion Bond Quality

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Signal Analysis Approach to Ultrasonic Evaluation of Diffusion Bond Quality

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Abstract

Solid state bonds like the diffusion bond are attractive techniques for joining dissimilar materials since they are not prone to the defects that occur with fusion welding. Ultrasonic methods can detect the presence of totally unbonded regions but have difficulty sensing poor bonded areas where the substrates are in intimate contact. Standard ultrasonic imaging is based on amplitude changes in the signal reflected from the bond interface. Unfortunately amplitude alone is not sensitive to bond quality. We demonstrated that there is additional information in the ultrasonic signal that correlates with bond quality. In our approach we interrogated a set of dissimilar diffusion bonded samples with broad band ultrasonic signals. The signals were digitally processed and the characteristics of the signals that corresponded to bond quality were determined. These characteristics or features were processed with pattern recognition algorithms to produce predictions of bond quality. The predicted bond quality was then compared with the destructive measurement to assess the classification capability of the ultrasonic technique

Introduction

Solid state bonding, in particular diffusion bonds, are an excellent way to join similar and dissimilar metals. They have the advantage over welding in that they do not melt the base metal and affect its properties. Also diffusion bonding can easily join dissimilar metals. The drawback to diffusion bonding is that there is no nondestructive method for measuring the strength of the bond (1, 2). Current nondestructive evaluation techniques easily detect total unbonded areas but low strength bond are usually judged to be a good bond. This work addresses the problem of measuring bond strength. The ultrasonic signal from a diffusion bond contains much information about the condition of the bond. Extracting that information is the goal of this work.

Figure 1 illustrates the approach to extracting bond strength information from the ultrasonic signal. The protocol produces a computer algorithm that will predict bond strength based on subtle changes in the ultrasonic waveforms. The first step is to fabricate samples with varying bond strengths. Ultrasonic data is then acquired from the samples and stored. Next the samples are destructively tested to measure their strengths. The ultrasonic data can now be related to the strength of a bond. The digitized ultrasonic signals are processed with various transform techniques to determine frequency content (3,4,5). Changes in the frequency spectra are quantified and a set of features is generated. This feature vector uniquely identifies the ultrasonic signal taken from a known bond sample. The feature sets are analyzed to develop automated algorithms based on statistical and neural network codes (6). These classifiers predict the bond

strength by extracting features from the ultrasonics signals that have been reflected by the bond interface. Then they input these features into a formula that combines the feature values with weighting constants and produces a bond quality number. This resulting bond quality number corresponds to the bond's failure strength.

Samples

A set of copper to aluminum diffusion bond samples were manufactured to produce samples with different bond strengths. These samples were made by electroplating the surfaces with an interlayer (copper or zinc), applying pressure to hold the substrates together, and elevating the temperature. Less than nominal strength was produced by modifying the previous steps. For example, weak bonds were fabricated by not electroplating the samples or by not elevating the temperature adequately. Table 1 lists the matrix of manufacturing variations we applied in making the diffusion bond specimens.

Data acquisition

The condition of the bonds for each of the specimens was determined by traditional ultrasonic C-scan imaging. The images, based solely on amplitude variations in the reflected signals, clearly display areas of total unbond. Amplitude alone does not indicate bond strength. Ultrasonic data for the process of measuring bond strength were not captured in the unbonded regions.

Ultrasonic waveforms were captured from each of the samples and stored for future processing. A high frequency, broadband transducer sent the ultrasonic energy into the sample and received the energy reflected from the top surface of the specimen and the interface. This procedure was done from the copper side and the aluminum side. Many ultrasonic signals were captured on each sample. The location of each signal was recorded so that the strength at that location could be correlated with the signal.

Destructive Analysis

After acquiring the ultrasonic data, the samples were cut into tensile specimens. These specimens were pulled to failure in a test apparatus and the failure strength was noted. These failure strengths were then correlated with the ultrasonic signals. Thus each ultrasonic waveform represented a known bond strength.

To better understand the bonding process, metallographic analysis was conducted on the diffusion bonds. Representative samples from each bond strength were potted and polished. The interface was imaged with a microscope and analysis of the interface correlated the amount of bonding with strength.

Figure 2 shows the micrographs from low, medium, and high strength bonds. The high strength bond displays a diffuse interface whereas the low strength bond shows an

obvious interface. Much more acoustic energy will be reflected from the low strength bond's interface.

Results

Ultrasonic signals contain information that corresponds with bond strength in copper to aluminum diffusion bonded samples. Figure 3 summarizes the results of this work. Example frequency spectra from low (1494 psi), medium (3235 psi), and high (6929psi) strength bonds are displayed in Figure 3. Also for comparison, the frequency spectrum for an area on a sample that was unbonded is shown. It has much more energy than the others. This is because an unbond reflects almost all of the acoustic energy. A high strength bond will only reflect the amount of energy predicted by the acoustic impedance mismatch between copper and aluminum. This is the case for the spectrum from the high strength bond. As expected the other levels of bond strength fall in between.

The goal of this work is for the computer to automatically predict the bond strength. To do this, the obvious differences in the spectra shown in Figure 3 must be quantified before the computer can predict the strength. One way to characterize the spectra is by measuring the area under the curve for particular frequency ranges. The energy under the curve at 15MHz is a feature that corresponds well with bond strength. Figure 4 plots failure strength verses spectral value at 15 MHz. These results show that the energy at 15MHz decreases as the failure strength increases.

The next task will be to develop an automated classifier that predicts the bond strength based on the optimal features. Statistical and neural network algorithms will process the feature vectors from a training set of ultrasonic data to evolve a diffusion bond classifier that predicts strength.

Summary

This work developed an ultrasonic technology to determine diffusion bond quality. After an ultrasonic signal interacts with a bond, it contains information about the quality of the interface. Copper to aluminum diffusion bonds were fabricated with known bond strengths. Ultrasonic data from these known samples were analyzed to determine characteristics of the signal that corresponded to changes in bond strength. An example of a characteristic that correlated with bond strength is the acoustic energy at 15 MHz. The value of this feature decreased as the bond strength increased.

References

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Table 1. A matrix of aluminum-copper bond samples allows us to study variations in bonds due to different surface preparations, bonding temperatures and bonding times.

Diffusion Bonding of Al to Cu

| Surface Condtions				Bonding Conditions, Plan/Actual		
Al	Cu	Al Sp#	Cu Sp#	Temp., C	Bonding Time, min.	Bond Pressure, psi
None	None	AlP2	CuP1	550/535*	60	175
None	None	AlP1	CuP2	550/535*	90	175
Zn	Zn	AlZn3	CuZn2	500	60	175
Zn	Zn	AlZn1	CuZn1	500	90	175
Cu	Zn	AlCu2	CuZn3	550/535*	90	175
Cu	Zn	AlCu5	CuZn4	500	90	175
Zn	None	AlZn4	Cu2	500	60	175
Zn	None	AlZn2	Cu4	500	90	175
Cu	None	AlCu4	Cu5	550	60	175
Cu	None	AlCu1	Cu1	550	90	175

*535C used instead of 550C
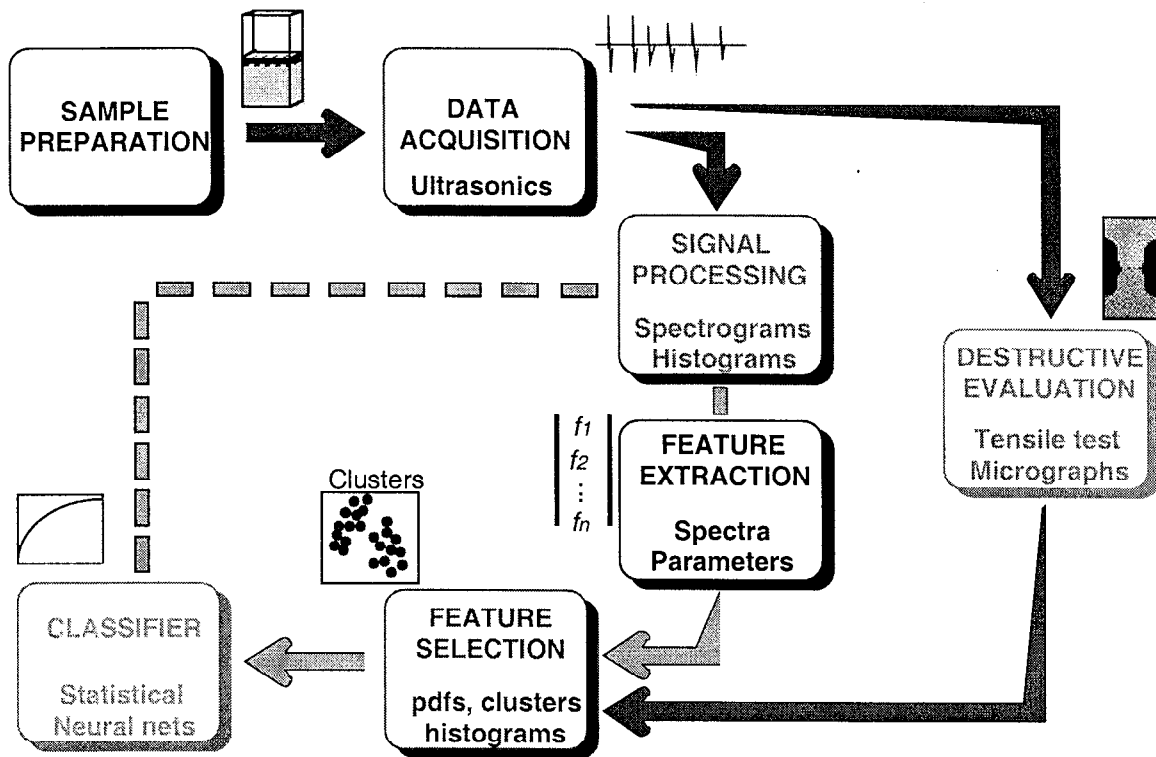
Figure 1. Protocol for bond strength classification trains an algorithm to predict diffusion bond strength based on subtle differences in the ultrasonic signals reflected by the bond.
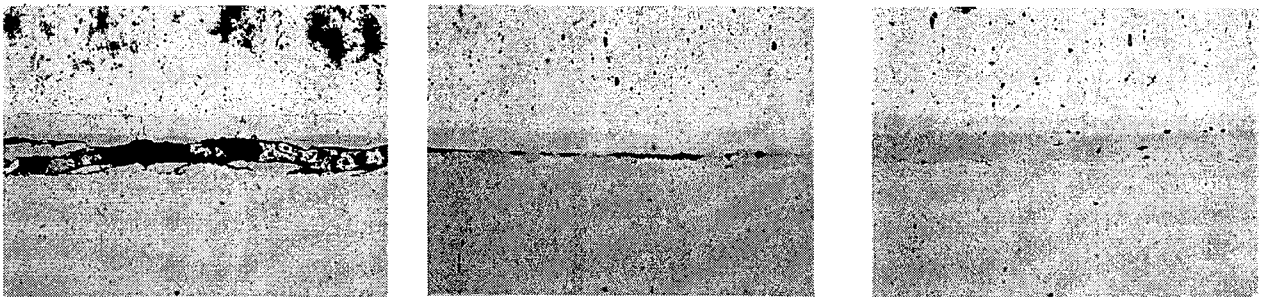

Figure2. Micrographs from low (1494 psi), medium (3235 psi), and high (6929 psi) strength diffusion bonds. Note: The high strength bond has a diffuse interface whereas the low strength bond has a distinct boundary.
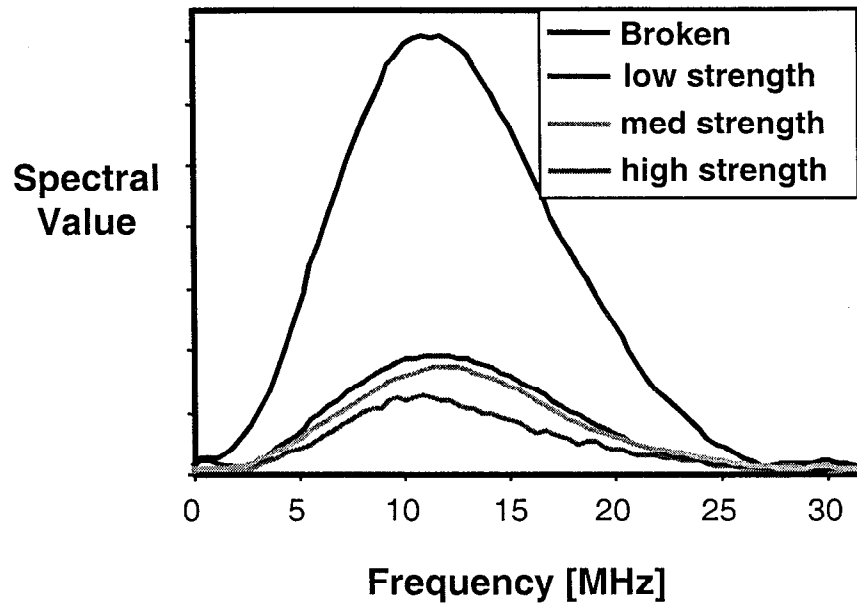
Figure 3. Frequency spectra from ultrasonic signals reflected from diffusion bonds shows decreasing spectral value for increasing bond strength.
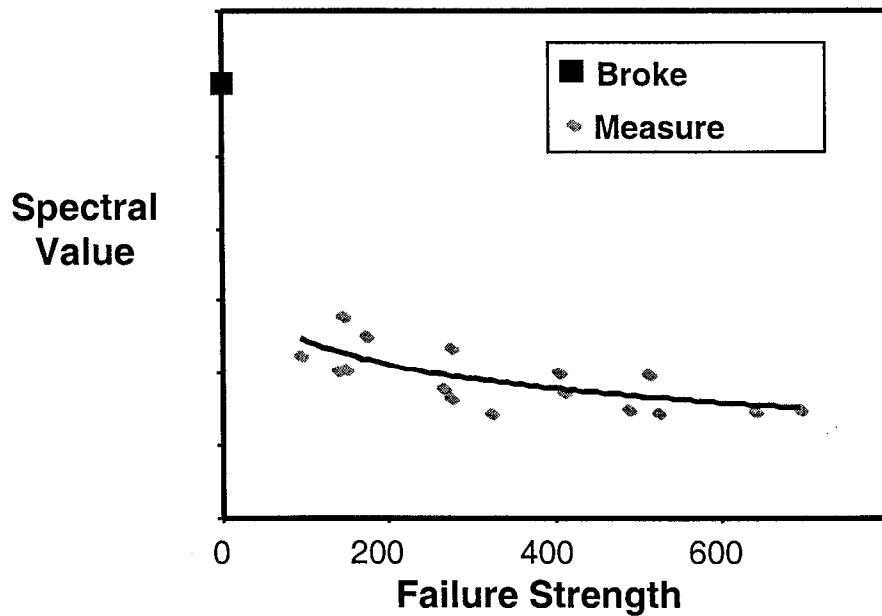

Figure 4. Spectral energy at 15 MHz decreases as the bond strength increases. The signal from the unbonded area has an extremely large amount of acoustic energy and thus is detectable by standard ultrasonic techniques.